Scientific Frontiers in Research on Extrasolar Planets
ASP Conference Series, Vol. 294, 2003
D. Deming and S. Seager, eds.

A Keck Adaptive Optics Search for Young Extrasolar Planets

Denise Kaisler, Ben Zuckerman, and Eric Becklin

Department of Physics and Astronomy UCLA, 8371 Math Sciences Bldg. Box 951562 Los Angeles, CA 90095-1562, kaisler@astro.ucla.edu

Bruce Macintosh

Institute for Geophysics and Planetary Physics, Lawrence Livermore National Labs, 7000 East Ave. L-413, Livermore, CA 94551

Abstract. Adaptive optics, large primary mirrors, and careful selection of target stars are the keys to ground-based imaging of extrasolar planets. Our near-IR survey is capable of identifying extrasolar planets of 1-10 M_J within 100 AU of young (t<60 Myr), nearby (d<60 pc) stars. For very young and proximate targets such as GJ 803 (12 Myr, 10 pc) we are able to detect extrasolar planets with parameters approaching those of planets our solar system (1 M_J at 19 AU, 2 M_J at 9 AU; 5 M_J at 5 AU). We have thus far imaged over 100 stars with Keck AO. Here we report on our progress, discuss specific observing strategies, and present detailed sensitivity limits.

1. Introduction

Direct detection is a crucial next step in our understanding of extrasolar planets. Although the radial velocity technique continues to generate valuable discoveries (Marcy & Butler 2000), the composition, origins, and essential natures of extrasolar planets will likely remain hidden unless we can study them directly.

To date, we know of over 100 extrasolar planets, all with semi-major axes < 6 AU. Using the radial velocity technique, detection of extrasolar planets with orbital radii similar to those of Saturn, Uranus, and Neptune would require timelines on the order of decades. However, the existence of the outer planets, theories of planetary dynamics (e.g., Rasio & Ford 1996), and the shaping of dusty debris disks (Holland et al 1998; Greaves et al. 1998; Liou & Zook 1999; Ozernoy et al. 2000) all lend credence to the idea of planets with semi-major axes of tens to hundreds of AU.

2. Strategies for Heightened Sensitivity

The primary requisites of a workable strategy for imaging of extrasolar planets are high-contrast and subarcsecond resolution. These capabilities are available via the use of ground-based adaptive optics (AO) systems or direct imaging from space. A choice of AO in turn mandates the use of large telescopes, since the time required to achieve a given S/N ratio varies as the inverse fourth power of mirror diameter (Olivier et al. 1997). Yet even with Keck AO, planets with semi-major axes of order tens of AU can be spatially resolved only around stars within $\sim$ 60 pc of Earth. Current AO sensitivities also rule out the detection of solar-age planets in reflected light, however, young ($<$ 60 Myr), warm planets may be seen via their near-infrared emission.

Selection of young targets is effected chiefly through the study of galactic space motions (U,V,W) in conjunction with excess emissions of stars. These may appear as X-rays, Hα and Ca II H & K emission, or far-infrared excesses (e.g., Spangler et al. 2001). Lithium absorption may also be an important youth indicator. Techniques for identifying young stars are further described in Zuckerman et al. (2001).

Once targets have been identified and observed, registration of long-exposure images and a process called unsharp-masking increase our sensitivity to point sources. Unsharp-masking is a process in which a smoothed version of an image is subtracted from the original so as to improve the contrast between the background noise and small-scale structure. As can be seen in the next section, unsharp-masking improves our sensitivity to point sources by as much as two magnitudes within 2" of a target star.

3. Project Status

Our study utilizes the AO system on Keck II (Wizinowich et al. 2000). Over the past two years, we have observed $\sim$ 100 nearby, young stars using KCAM, NIRSPEC's slit-view camera (SCAM), and most recently NIRC2, the first camera optimized for Keck AO. We estimate that more than half of our target stars are $<$ 100 Myr old.

Figure 1 shows sensitivity calculations for representative targets from the SCAM and NIRC2 datasets. As expected, sensitivity improves both for NIRC2 data and for images which have been unsharp-masked.

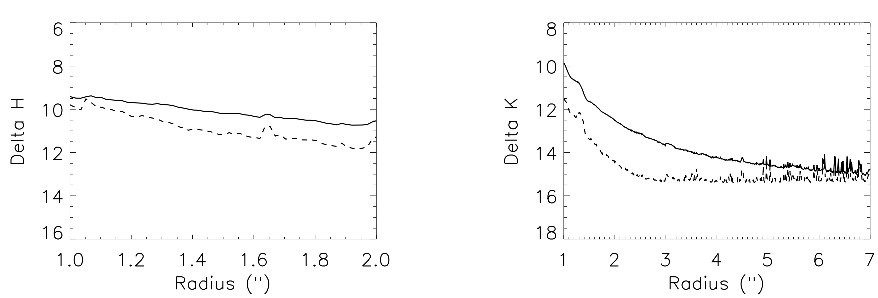

Figure 1. Sensitivity profile for (left) GJ 803 (H = 5.2, Strehl = 0.15 at H) taken with SCAM and BD+483686 (H = 6.6 , Strehl = 0.45 at K') taken with NIRC2. The solid lines represent 5-σ detection limits for a mosaic of sixteen 30-second images. The dashed lines show the improvements in sensitivity brought about by unsharp-masking.

Table 1. Planetary Detection Limits at Representative SCAM Stars

Star	d (pc)	age (Myr)	Strehl	Band	2 M_J R (AU)	5 M_J R (AU)	10 M_J R (AU)
GJ803	10	12	.15	H	9	5	3
HD207129	16	30	.10	H	32	16	10
HIP 560	39	12	.40	K'	78	35	23
HIP82587	30	30	.20	H	N/D	37	25
HD159911	$\sim$60	30	.40	K'	N/D	54	30

Using the age of GJ 803, we derived orbital separations at which this study would detect planets of 2, 5, and 10 Jupiter masses. By scaling with respect to star age and data quality (measured by Strehl ratio), we may extend this result to other target stars (Table 1).

Our sensitivity to planets of a given mass varies with such factors as age, distance, and magnitude of the host star, as well as conditions under which the data were taken. However, for the best stars in our sample, of which GJ 803 is an example, this survey is able to detect 1 M_J planets with orbital radii of only 19 AU.

Acknowledgments. Portions of this work were performed under the auspices of the U.S. Department of Energy, National Nuclear Security Administration by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48. This work was also supported by the National Science Foundation Science and Technology Center for Adaptive Optics, managed by the University of California at Santa Cruz under cooperative agreement No. AST - 9876783. Additional funding was provided by a NASA Origins grant to UCLA.

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